GMINUS2

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1 The $g-2$ experiment at Fermilab

The new $g-2$ experiment at Fermilab (E989) plans to measure the muon anomaly $a_\mu = (g-2)/2$ to an uncertainty of 16×10^{-11} (0.14 ppm), derived from a 0.10 ppm statistical error and roughly equal 0.07 ppm systematic uncertainties on ω_a and ω_p. The proposal efficiently uses the unique properties of the Fermilab beam complex to produce the necessary flux of muons, which will be injected and stored in the (relocated) muon storage ring. To achieve a statistical uncertainty of 0.1 ppm, the total data set must contain more than 1.8×10^{11} detected positrons with energy greater than 1.8 GeV, and arrival time greater than 30 μs after injection into the storage ring.

With a higher expected beam rate, more rapid filling of the ring, and even more demanding goals in systematic uncertainties, the collaboration has had to devise improved instrumentation. The ring kicker-system will be entirely new, optimized to give a precise kick on the first turn only, to increase the storage fraction. The magnetic field will be even more carefully prepared and monitored. The detectors and electronics are entirely new, and a state-of-the-art calibration system will ensure critical performance stability throughout the long data taking periods. New in situ trackers will provide unprecedented information on the stored beam. The first physics data-taking is expected in late 2017.

2 The Laser Calibration system

The $g-2$ experiment will require a continuous monitoring and re-calibration of the detectors, whose response may vary on both a short timescale of a single beam fill, and a long one of accumulated data over a period of more than one year. It is estimated that the detector response must be calibrated with relative accuracy at sub-per mil level to achieve the goal of the E989 experiment to keep systematics contributions due to gain fluctuations at the sub-per mil level on the beam fill scale (0-700 μs) and at the sub per cent level over the longer data collection period. This is a challenge for the design of the calibration system because the desired accuracy is at least one order of magnitude higher than that of all other existing, or adopted in the past, calibration systems for calorimetry in particle physics.

As almost 1300 channels must be kept calibrated during data taking, the proposed solution is based on the method of sending simultaneous light calibration pulses onto the readout photo-detector through the crystals of the calorimeter. Light pulses should be stable in intensity and timing in order to correct for systematic effects due to drifts in the response of the crystal readout devices. A suitable photo-detector system must be included in the calibration architecture to monitor any fluctuation of the light. The guidelines given by the experiment to define in the correct way the architecture of the entire system could be found in [1]. A sketch of the actual design of the calibration system is shown in Fig. 1. The crucial point for the realization of this

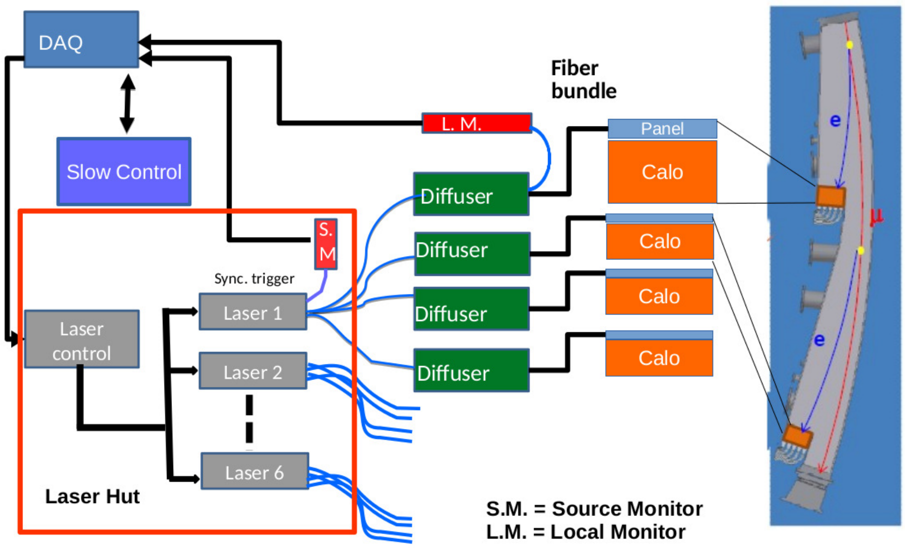

Figure 1: Schematic view of the Laser Calibration System design.

system are: the light source, the distribution system that shares the light to the calorimeters with sufficient intensity and sufficient homogeneity among them. The light source should be in the same spectral range accepted by the photodetectors and has to be powerful enough to ensure a sufficient amount of light for each calorimeter station considering losses due to the distribution chain.

3 GMINUS2 Activity in 2016

The LNF activity in 2016 has been focused on:

- Tests of the prototype Laser calibration system with beams (Frascati and SLAC).

  A test of the laser calibration system and the full light distribution chain using a 5-element calorimeter prototype was performed (February-March 2016) at the Beam Test Facility, Laboratori Nazionali di Frascati, with a 450 MeV electron beam. All components of the laser calibration system (except for the source monitor and local monitor frontend electronics) were those which will be used for the Muon g-2 experiment at FNAL. Details are given in [A. Anastasi et al., Electron beam test of the calibration system for the muon g 2 experiment Nucl. Instrum. Meth. A, 842 (2017) 86-91].

  Figure 2, left, shows the main results of the Frascati test beam: the SiPM signals from electrons (black) and laser (purple). The red crosses represent the SiPM signals corrected for the two monitors. A test of the laser calibration system and the full light distribution chain using a complete 54-crystal calorimeter was performed at ESTB facility in SLAC (June 2016). Both the final version of the in-house electronics developed by the Italian collaboration and the waveform digitizers developed for the experiment were used for the monitor detectors (PiDs and PMTs), while waveform digitizers were used for the calorimeter SiPMs. The laser

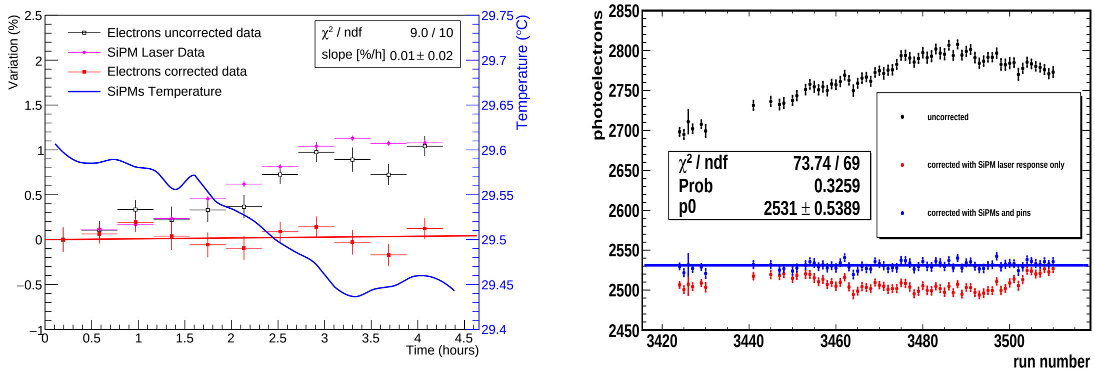

Figure 2: Left: SiPM response to electrons (black) and laser (purple) at Frascati Test Beam. Red crosses are the electrons signal corrected for bias drift, laser intensity fluctuations and transmission efficiency. The linear fit to corrected data shows no residual slope within statistical uncertainty. Right: SiPM response to electrons (black) at SLAC. Red points are corrected with laser pulses as reference. Blue points are further corrected for laser intensity variability with the source monitor Schematic view of the Laser Calibration System design.

control system, designed to study how the SiPM gain changes with luminosity was also tested. The beam particles were 3 GeV electrons, for most of the time, but 2.5, 3.5, 4.0, 4.5, and 5.0 GeV electrons were also used. Analysis of the collected data is ongoing. Results confirm those of the LNF test beam: correction with the monitor appears to be effective, see Fig. 2, right. The gain drift is corrected completely within statistical uncertainty. Details are given in [A.T. Fienberg et al., Performance of the instrumentation for measuring the anomalous precession frequency in the Fermilab Muon g-2 experiment JINST, to be submitted (2016)].

- Assembly of the Laser calibration system.

  In July 2016 the assembling of the laser calibration system started at Fermilab. Figure 3, left, shows the material delivered in June to the assembling room at Dzero hall at Fermilab.

- Light distribution panels.

  Each fiber will be routed to each crystal through a front panel done in Delrin, which contains 54 optical prisms in N-BK7. The mechanical workshop at LNF milled the 25 panels made of Delrin, according to the drawing shown in Fig. 3, right. Figure 4 shows the panels before and after right-angle prisms were glued to the plates.

- Local Monitors electronic boards.

  A second monitoring system (local monitor or LM) is provided by bringing one of the optical fibers of the bundle back to the laser hut by means of 24, 25 m-long PMMA fibers. The LM monitors light power variations over time, occurring between the laser head and the end tip of the bundle. LM PMT gains are calibrated by comparing the intensity of a laser pulse that comes back from the end of the distribution system with the intensity of a laser pulse extracted from the SM in the same PMT. The two laser pulses are separated in time by 250 ns because of their different path lengths. The schematics of the LM electronic board is shown in Fig 5.

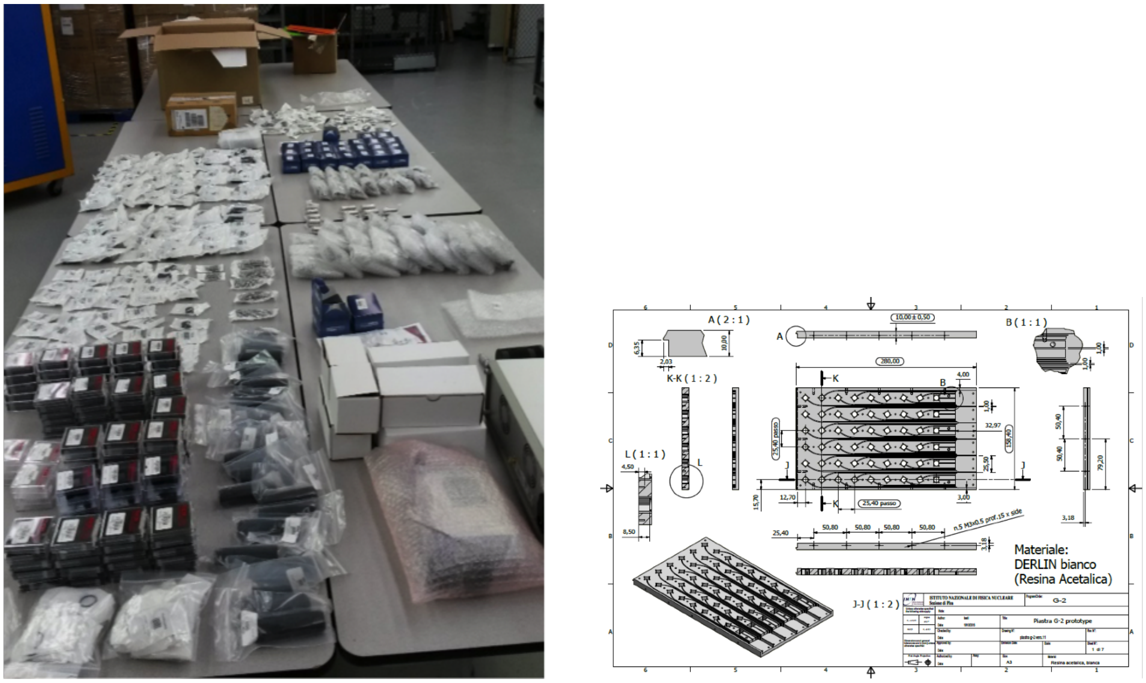

Figure 3: Left: Material delivered to the assembling room at Dzero at Fermilab. Right: Technical drawing of the light distribution plate.

4 List of Conference Talks, Posters by LNF Authors in Year 2016

1. A. Anastasi, "The calorimeter System of the new muon g-2 experiment at Fermilab", Poster at the 14^{TH} Vienna Conference on Instrumentation, Vienna, Austria, 15-19 February 2016.
2. E. Rossi, "Il sistema di calibrazione laser dell'esperimento g-2 al Fermilab" (*In Italian*), 102^{o} Congresso Società Italiana di Fisica, Padova 26-30 September 2016.
3. C. Gabbanini "The laser calibration system", MUSE General Meeting, Pisa, Italy, 29 September 2016.
4. G. Venanzoni "The New Muon g-2 experiment at Fermilab (E989)", MUSE General Meeting, Pisa, Italy, 29 September 2016.

5 List of Papers/Proceeding/notes

1. J. Kaspar *et al.*, "Design and performance of SiPM-based readout of PbF2 crystals for high-rate, precision timing applications", *submitted for publication to JINST in 2016*
2. A. Anastasi *et al.*, "Electron Beam Test of Key Elements of the Laser-Based Calibration System for the Muon $g-2$ Experiment", *submitted for publication to Nucl. Instrum. Meth. A in 2016*
3. L. P. Alonzi *et al.*, "The calorimeter system of the new muon g -2 experiment at Fermilab," Nucl. Instrum. Meth. A **824** (2016) 718.

Figure 4: Light distribution planes before and after right-angle prisms were glued to the plates.

4. A. Anastasi *et al.*, “The calibration system of the new g 2 experiment at Fermilab,” Nucl. Instrum. Meth. A **824** (2016) 716.

5. G. Venanzoni *et al.*, “Proceedings, Workshop on Flavour changing and conserving processes 2015 (FCCP2015) : Anacapri, Capri Island, Italy, September 10-12, 2015,” EPJ Web Conf. **118** (2016).

6. A. Anastasi *et al.*, “The Muon g-2 laser calibration system”, E989 Note 98, 2016.

References

1. A. Anastasi *et al.*, “Test of candidate light distributors for the muon (g-2) laser calibration system”, Nucl. Instum. Meth. A**788** (2015) 43-48.

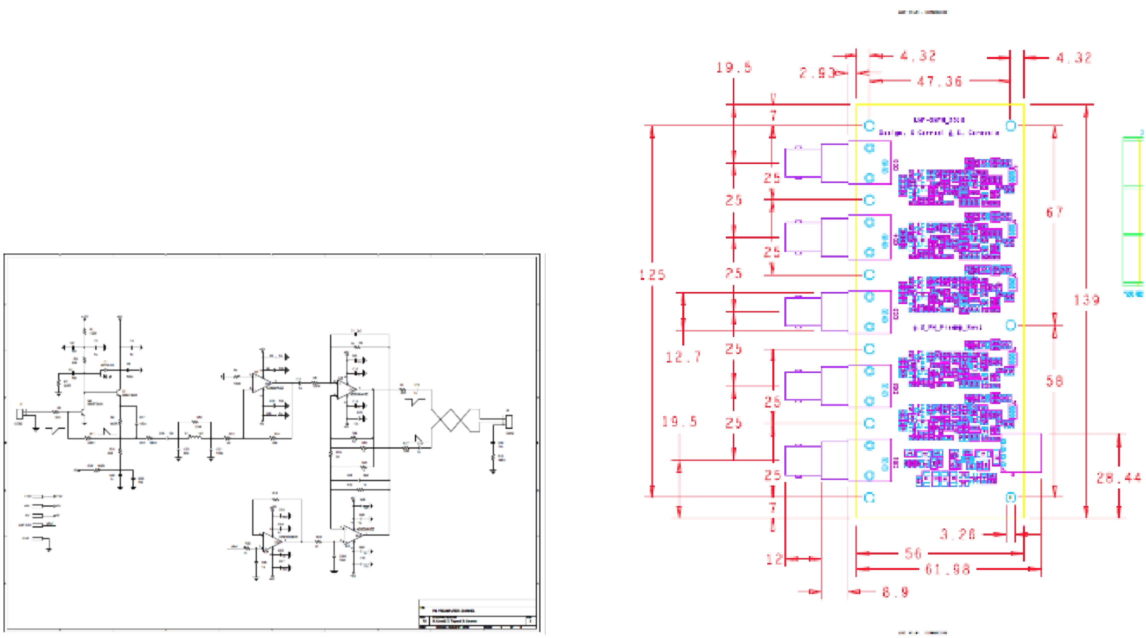

Figure 5: The local monitoring electronic board: (Left) single channel scheme; (Right) 5 channels layout.Local Monitor electronics boards